

J-92-05

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MARCH 1992

PROGRAM TRENDS: IMPLEMENTATION OF A POWER ANALYSIS FOR DETECTING TRENDS

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ADMINISTRATIVE REPORT LJ-92-05

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**Program TRENDS: Implementation of
a power analysis for detecting trends**

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ABSTRACT

A microcomputer-based program implements the power analysis for detecting trends in abundance described in Gerrodette, Ecology 68: 1364-1372 (1987) and Gerrodette, Ecology 72: 1889-1892 (1991). Program TRENDS is simple to use and allows easy calculation of statistical power, number of sampling occasions, sample precision, and detectable rate of change in abundance. This manual describes program structure, outlines numerical techniques, gives examples of program use, and lists error messages.

STATEMENT OF THE PROBLEM

Gerrodette (1987, 1991) described an approach for conducting a power analysis for detecting trends in abundance. The numerical solution of the equations given in those papers, however, is not trivial, particularly if the calculations are based on the t distribution. Program TRENDS is a user-friendly program to carry out those calculations. The program structure makes it easy to see the effect of altering various parameters on the value of the computed parameter of interest. Program TRENDS should be useful to practicing scientists in designing field studies. It could also be useful to students in a course on field methods or experimental design.

The approach implemented here assumes that we plan to make a series of independent estimates of abundance of some quantity of interest, at equal intervals in time or space, and following the same methods of estimation on each sampling occasion. A trend in abundance is to be evaluated by regressing the estimates against time or distance. Such an experimental design will usually satisfy the assumptions of linear regression closely, with two important exceptions:

- (1) If the nature of the process of change is multiplicative rather than additive, points will not be linear but will lie along an exponentially increasing or decreasing curve. This is a common situation for many practical problems of interest. A logarithmic

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transformation of the estimates will make them linear, and such a transformation usually has the additional positive effect of making the variances more nearly equal. Program TRENDS allows the user to choose between linear and exponential models of change.

(2) Even if equal effort and identical methods are used on each sampling occasion, the variances of the estimates will in general not be equal, as required by linear regression, but will be some function of abundance A . The situations treated here, which correspond to common methods of estimating population size, let the variance be proportional to A , A^2 , or A^3 (Gerrodette 1987). In program TRENDS this is implemented by having the user choose among 3 patterns of change of coefficient of variation ($CV = \text{standard error}/\text{mean}$) with abundance: CV proportional to $A^{-1/2}$, CV constant with A , or CV proportional to $A^{1/2}$.

Another factor to consider is whether, on each sampling occasion, the method of estimation or measurement produces a single estimate of A , or whether an estimate of $\text{var}(A)$ is also produced. If estimates of A only are produced, we have the classical regression problem and use the t distribution with $n-2$ degrees of freedom to analyze this situation. If, however, variance estimates are also produced, we use the z distribution. Use of the z distribution actually assumes the $\text{var}(A)$ are known, not estimated. This will rarely if ever be true, but if the estimates of A and $\text{var}(A)$ are based on a reasonably large number of observations, we can consider the number of degrees of freedom to be large, and the z distribution will provide a sufficiently accurate basis for

calculation (Gerrodette 1991). However, users should be aware that use of the z distribution is less conservative -- i.e., it will always give more optimistic answers.

Gerrodette (1987, 1991) summarized the problem in 5 parameters: n , the number of sampling occasions; r , the rate of change in abundance that occurs between each sampling occasion; CV_1 , the coefficient of variation of the first estimate of abundance in the series; α , the significance level (probability of Type 1 error); and the statistical power ($1 - \beta$, where β is the probability of Type 2 error). Any one of these can be calculated if the other 4 are specified. Which parameter is of primary interest will depend on the application.

The relations among these parameters are affected by a number of factors. Factors treated here are: (1) whether change is linear or exponential; (2) whether change is positive or negative; (3) whether the statistical test is 1- or 2-sided; (4) how the precision of the estimates depends on abundance; and (5) whether the standard normal (z) or Student's (t) distribution is used in the calculations.

More general approaches along the lines suggested in section (3) of Gerrodette (1991) are not implemented at this time. Future additions could allow sampling at unequal intervals, arbitrary patterns of variance, detection of nonlinear patterns, and correlation among estimates.

PROGRAM STRUCTURE

Program TRENDS is written in Microsoft FORTRAN 77 and the executable file will run on an IBM-compatible microcomputer. The main driver is an I/O interface that calls subroutine TREND, which carries out the calculations. Subroutine TREND, together with its supporting subroutines and functions, could be used in another user-written main program, if desired. TREND requires 2 specific external functions (FXL and FXE), 2 subprograms to compute the z and noncentral t cumulative distribution functions (CUMPR and PRNCT), and 2 subprograms to compute the inverses of those distribution functions (ZINV and TINV). Users could substitute their own routines for the latter 4 if desired.

The basic equations to be solved are

$$1-\beta = \Phi \left(z_{\alpha} - \frac{b}{\sigma_b} \right)$$

for a decreasing trend ($b < 0$),

$$1-\beta = \Phi \left(\frac{b}{\sigma_b} - z_{1-\alpha} \right)$$

for an increasing trend ($b > 0$), and

$$1-\beta = \Phi \left(z_{\alpha/2} - \frac{b}{\sigma_b} \right) + \Phi \left(\frac{b}{\sigma_b} - z_{1-\alpha/2} \right)$$

for a trend in either direction. If the z distribution is used, as above, Φ is the distribution function for the standard normal

distribution. If the t distribution is used, replace z_α by $t_{\alpha, n-2}$ in the equations above, and let Φ be the distribution function for the noncentral t distribution. b is the expected value of the true slope of the regression line and σ_b its standard deviation; both are functions of r , n , and $CV1$. The exact expressions for b and σ_b as functions of r , n , and $CV1$ depend on the model of change (linear or exponential) and the pattern of change of CV with abundance, and are complicated (Link and Hatfield 1990). However, approximations given in Gerrodette (1987) are satisfactory for most cases and are used here. Roots are located with a tolerance of 0.001 using Brent's method (Press et al., 1989), slightly modified as ZBRENT. Initial root bracketing is accomplished with ZBRAC, another routine slightly modified from Press et al. (1989).

Program TRENDS accepts input either interactively or from an input file named TRENDS.INP. As values are given interactively, an input file is created so that runs can be repeated, or single values can be changed easily. Before computations are started, the program displays the input values and gives the user the opportunity to change any of them. Output is displayed on the screen and also saved in a file named TRENDS.OUT.

EXAMPLE

The following example is based on the sea otter example described on p. 1368-69 of the 1987 paper. User input is given in bold lettering and is case insensitive.

TRENDS

[Header appears]

One of the following parameters can be computed:

- (1) number of samples (n)
- (2) rate of change (+/- r)
- (3) initial coeff. of variation (CV1)
- (4) significance level (alpha)
- (5) power (1-beta)

Enter value for index of parameter to be computed: **5**

[Power is selected, so program
now prompts for other values]

Enter value for number of samples (n) : **5**

Enter value for rate of change (+/- r) : **.1**

Enter value for initial coeff. of variation (CV1): **.13**

Enter value for significance level (alpha) : **.05**

Enter value for 1- or 2-tailed test : **2**

Enter value for model (1=linear, 2=exponential) : **2**

1=CV proportional to $1/\sqrt{A}$

2=CV constant with A

3=CV proportional to $\sqrt{A}$

Enter value for pattern of CV with abundance A : **1**

1=use z distribution (variance assumed known)

2=use t distribution (variance est. from residuals)

Enter value for distribution index (1=z, 2=t) : **1**

[Input is complete; program displays
input values and prompts for change]

You have specified the following input values:

(1)	5	number of samples (n)
(2)	.100	rate of change (+/- r)
(3)	.130	initial coeff. of variation (CV1)
(4)	.050	significance level (alpha)
(5)	(to be computed)	power (1-beta)
(6)	2	1- or 2-tailed test
(7)	2	model (1=linear, 2=exponential)
(8)	1	pattern of CV with abundance A
(9)	1	distribution index (1=z, 2=t)

To proceed with these values, press ENTER;
to change one of them, enter the line number: <ENTER>

*** PROGRAM TRENDS OUTPUT ***

Model of change: EXPONENTIAL
Pattern of variance: CV PROPORTIONAL TO 1/SQRT(A)
Calculation based on Z distribution
Alpha = .050 (2-tailed)
Rate = .100
CV = .130
Sample size = 5

Given these parameters, power is .722

Do you wish to try another calculation? (Y/N) y

[We'll try another combination]

You have specified the following input values:

(1)	5	number of samples (n)
(2)	.100	rate of change (+/- r)
(3)	.130	initial coeff. of variation (CV1)
(4)	.050	significance level (alpha)
(5)	(to be computed)	power (1-beta)
(6)	2	1- or 2-tailed test
(7)	2	model (1=linear, 2=exponential)
(8)	1	pattern of CV with abundance A
(9)	1	distribution index (1=z, 2=t)

To proceed with these values, press ENTER;
to change one of them, enter the line number: 2

[We ask to modify the rate of change]

Enter value for rate of change (+/- r) : -.1

[The rate is changed to a 10% decline]

You have specified the following input values:

(1)	5	number of samples (n)
(2)	-.100	rate of change (+/- r)
(3)	.130	initial coeff. of variation (CV1)
(4)	.050	significance level (alpha)
(5)	(to be computed)	power (1-beta)
(6)	-2	1- or 2-tailed test
(7)	2	model (1=linear, 2=exponential)
(8)	1	pattern of CV with abundance A
(9)	1	distribution index (1=z, 2=t)

To proceed with these values, press ENTER;
to change one of them, enter the line number: <ENTER>

*** PROGRAM TRENDS OUTPUT ***

Model of change: EXPONENTIAL
Pattern of variance: CV PROPORTIONAL TO 1/SQRT(A)
Calculation based on Z distribution
Alpha = .050 (2-tailed)
Rate = -.100
CV = .130
Sample size = 5

Given these parameters, power is .635

[Note the asymmetry in power between
increasing and decreasing trends]

Do you wish to try another calculation? (Y/N) n

Results for this run are stored in TRENDS.OUT.

[Exit TRENDS, return to system control]

At the conclusion of the run, the file TRENDS.OUT contains the results of all calculations, and the file TRENDS.INP contains the input values for the last calculation. For the example run above, the input file would now be:

```

5          index of parameter to be computed
5          number of samples (n)
-.100      rate of change (+/- r)
.130       initial coeff. of variation (CV1)
.050       significance level (alpha)
(to be computed) power (1-beta)
-2         1- or 2-tailed test
2          model (1=linear, 2=exponential)
1          pattern of CV with abundance A
1          distribution index (1=z, 2=t)

```

Notice that the first record indicates the parameter to be computed, but this is not displayed on the screen. The input file can be edited directly with any ASCII editor, but this is not recommended because it will bypass the error checks within the program.

Careful readers may note small numerical differences between the results of TRENDS and some graphs and tables in Gerrodette (1987) and Holt et al. (1987). These are due to improvements to the code and the correction of one bug. The bug affected the calculations of power for small effects in the 2-tailed case. Note the different y-intercepts of the 1- and 2-tailed curves in Fig. 3 of Gerrodette (1987). These should be the same, and equal to the Type 1 error rate (0.05 in this case). The current program has corrected this bug.

The sign of line 2 (rate of change) and line 6 (1- or 2-tailed

test) should always be the same; the program will enforce this. The reason for using a sign on line 6 occurs when r is the parameter to be estimated. The user indicates whether the positive or negative solution for r is desired by the sign given on line 6. Solutions for increasing and decreasing trends will generally be different, as the example run shows.

The results are to be interpreted as follows:

If the parameter to be computed is	the answer means that
n	n is the minimum number of sampling occasions that are needed at the given error rates; the number of sampling intervals is $n-1$
r	r is the minimum rate of change (per sampling interval) that can be detected at the given error rates
CV1	CV1 is the maximum permitted CV (minimum required precision) for the initial sample at the given error rates; CVs change with samples according to the pattern specified on line 8
α	α is the probability of obtaining a significant trend (slope $\neq 0$) falsely (Type 1 error)
power	power is the probability of obtaining a significant trend (slope $\neq 0$) correctly ($= 1-\beta$, where β is the probability of Type 2 error)

ERROR CONDITIONS AND POSSIBLE PROBLEMS

Program TRENDS will calculate an answer for reasonable values of the parameters, but it is impossible to anticipate all possible situations. For some combinations of parameters, no numerical solution is possible. For others, particularly very large or very small values of the parameters, underflow, overflow, or other numerical problems may occur. These will be indicated by run-time error messages. In this case, try less extreme values. The program also has a number of error traps. Most impermissible values will be caught on input, but if not, they may be detected by subroutine TREND, which returns the following error codes:

IER	Error condition
1	wrong parameter chosen (must be 1-5)
2	number of samples (n) too small
3	rate of change (r) = 0
4	intial CV ≤ 0
5	$\alpha \leq 0$ or ≥ 1
6	power ≤ 0 or ≥ 1
7	tails for test $\neq 1$ and $\neq 2$
8	model of change $\neq 1$ and $\neq 2$
9	change of CV with A < 1 or > 3
10	choice of z or t distribution $\neq 1$ and $\neq 2$
11	wrong tail of distribution (r and ITAIL have opposite signs)
12	root not bracketed, hence not found

If the program is used for input, the first 11 errors should not occur. Attempts to input values out of range will trigger error messages and the user will be prompted for a new value. If input file TRENDS.INP is edited directly, no checking occurs until

subroutine TREND is called, so any of these messages may appear. IER = 12 means that the program was unable to solve for a root. The combination of input values either does not permit a solution, or is so close to one of the boundary conditions that problems were encountered. Try again with less extreme values.

Problems encountered when using this program should be reported to the author, together with the input file used.

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